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# Worldwide Comparison of CO<sub>2</sub>-EOR Conditions

Comparison of fiscal and industrial conditions in seven global regions where CO<sub>2</sub>-EOR is active or under consideration

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The views and opinions expressed by authors in this publication are those of the authors and do not necessarily reflect those of the project sponsors.

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## 1. Introduction

Previous work within the Scottish Carbon Capture & Storage (SCCS) joint industry project (JIP) on carbon dioxide enhanced oil recovery (CO<sub>2</sub>-EOR) which looked at financial incentives for CO<sub>2</sub>-EOR in the United Kingdom (UK) suggested that development of an EOR project in the UK continental shelf area was most likely only to be considered by a super-major or multinational oil company (Durusut and Pershad, 2014). For such a project to be initiated the overall conditions for CO<sub>2</sub>-EOR – financial, policy, industrial – would need to be equivalent or favourable compared to other oil-producing regions, otherwise investments would likely be made elsewhere.

The purpose of this work package was to compare such conditions between seven major oil-producing regions that either are already, or are considering using CO<sub>2</sub>-EOR to increase oil outputs. The regions chosen were:

- United States of America (USA) onshore
- USA Gulf of Mexico
- Canada
- Malaysia
- China
- Norway
- UK

This report covers initial, desk-based research to compare regional conditions for CO<sub>2</sub>-EOR developments focussing in particular on tax regimes and also covering CO<sub>2</sub> supply availability and CO<sub>2</sub> transport infrastructure. Other areas of comparison – energy policies, regulatory conditions and government support – are not covered in this report but may be included in further studies.

The following two sections summarise the main findings of the regional comparisons covering firstly, taxes and incentives, and secondly, CO<sub>2</sub> supply status and industry experience. A short concluding section follows providing a degree of overview.

## 2. Comparison of tax regimes by region

This section compares the tax regimes across the seven regions of interest covering the bases on which taxes are charged (royalties, corporate income tax, production taxes and other special taxes), tax rates and information on specific tax incentives for EOR. The key reference used for much of the information in this section is the Ernst and Young (2014) *Global Oil and Gas Tax Guide*.

### 2.1. Tax bases and rates

Taxes and other charges for oil production activities can, to a first approximation, be divided into two groups: (1) those applied on the basis of production volume or value and (2) those applied on the basis of net income from the operation. The balance between these groups, as well as the rates applied and incentives allowed, differ between jurisdictions. Table 1 summarises the main differences in oil taxes between regions using these groupings. Royalties, although not formally a tax, are included in the first group.

As can be seen from the ranges and differences of detail summarised in Table 1, which are simplified in most cases, it is difficult to make a straightforward comparison between the regions. Corporate income taxes are significantly lower in North America and Asia than they are in the North Sea jurisdictions, and differences in ring-fencing accentuate this, particularly for the UK. But the royalties and production-value-based taxes in North America and Asia, while having lower rates, will likely be paid on significantly higher values than income taxes. Where the balance lies, in terms of which regime leads to higher or lower taxes, will depend on the individual project and company involved and is beyond the scope of this report.

### 2.2. Incentives for EOR

Incentives for development of CO<sub>2</sub>-EOR projects are offered in the USA, Canada and Malaysia; these incentives are described below and summarised in Table 2.

#### 2.2.1. USA

In the USA the federal tax regime (applicable both on- and offshore) has provided a notional credit of 15% of allowable costs of CO<sub>2</sub>-EOR, but only when oil prices are low, as judged each year (Pirog, 2013). This credit has not been available since 2006 due to high prices (KPMG, 2014) and it is not yet clear if the current low prices will revive it. The expenses of tertiary injection, including costs of CO<sub>2</sub>, have also been fully deductible. In 2013 the Obama Administration proposed to repeal these incentives, along with numerous other tax incentives, for the Financial Year 2014 Budget Proposals (Pirog, 2013).

Separately, there are federal tax credits available to companies who capture anthropogenic CO<sub>2</sub> for supply into the CO<sub>2</sub>-EOR market (at \$10/t-CO<sub>2</sub>) or for geological sequestration (at \$20/t-CO<sub>2</sub>) (USGPO, 2012). These credits are designed to increase the supply of CO<sub>2</sub> captured from power generation or industrial facilities such that the cost of CO<sub>2</sub> is maintained at a level that makes CO<sub>2</sub>-EOR developments attractive; this is seen as preferable to direct support to oil companies for EOR. The existing credits are limited to a total of 75 million tonnes (Mt) of CO<sub>2</sub>, of which over 21 Mt had been allocated by mid-2014. In 2014 a bill was proposed to remove the limit for this credit and improve the administrative procedures involved (Snow, 2014) following recommendations from an advocacy group, the National Enhanced Oil Recovery Initiative (NEORI, 2012a; NEORI 2012b).

It is not immediately clear whether either of these groups of proposals have been enacted.

**Table 1. Oil taxes compared**

Region	Taxes applied to production value		Taxes applied to net income	
	Summary, % prodn. value	Details	Summary, % net income	Details
<b>USA onshore</b>	12 - 38	Royalty – 12-30%, paid to rights owner, rate negotiated or result of bidding. Severance Tax – rates and tax base detail vary with state, generally based on gross production value at wellhead, rates e.g. Texas 4.6%, Alabama 8%. Alaska is different, 25% based on net value at pipeline end.	35	Combined federal and state rate against net cash income; state rate 0-12%, essentially deductible from federal rate. Not ring-fenced, can offset losses/deductions across whole company and value chain.
<b>USA Gulf of Mexico</b>	18.75 - 26.75	Royalty – 18.75% since March 2008. Previously 16.7% or, earlier, 12.5%. Severance Tax – only applies in state waters, rates and bases vary as for onshore.	35	Combined federal and state rate against net cash income; state rate 0-12%, essentially deductible from federal rate. Not ring-fenced, can offset losses/deductions across whole company and value chain.
<b>Canada</b>	10 - 45	Royalty – Crown Land royalties vary 10-45%; freehold royalties vary also, no detail found.	25-31	Federal rate (2013) 15%, state rate varies 10-16%. Charged on net income at corporate level, no ring-fencing.
<b>Malaysia</b>	10	Developers require Production Sharing Contract (PSC) with PETRONAS, who take first 10% of volume as royalty, plus share of 'profit oil' negotiated under contract. Also 'signature bonus' paid to PETRONAS for contract. PSC not required in Malaysia-Thailand Joint Development Area (JDA).	38	Petroleum Revenue Tax (PRT) charged at 38% on net income from production and transport operations within Malaysia. Other operations subject to Income Tax of 25%. Lower PRT rates and progressive with time in JDA; arrangements in place with Thailand to avoid double taxation in JDA.

Continued...

**Table 1 Continued. Oil taxes compared**

Region	Taxes applied to production value		Taxes applied to net income	
	Summary, % prodn. value	Details	Summary, % net income	Details
<b>China</b>	6 - 21.5 or more	PSC required, 'signature bonus' payable to state. Royalty – up to 12.5% for PSC prior to Nov.2011. Resource Tax – 5% of sales revenue offset by VAT and various exemptions, since Nov.2011. Mineral resources compensation fee – 1% of sales revenue. Special Oil Gain Levy – 20-40% of value above \$55/bbl, i.e. progressive from 0% at \$55/bbl to 15.5% at \$100/bbl, and more for higher barrel values.	25	Many expenses including other taxes and levy deductible before income tax.
<b>Norway</b>	0	No royalty.	78	Corporate Income Tax (CIT) 27%, on net operating profits. Resource Rent Tax 51%, on net operating profits of offshore extractive and transportation activities, including onshore supporting activities. Charged at corporate level, not ring-fenced, but limits to transfers of deductions between on- and offshore activities.
<b>UK</b>	0	No royalty.	50-75	Corporation Tax (CT) 30%, on profits from oil and gas exploration and production, ring-fenced, cannot offset losses in other parts of company/value chain. Supplementary Charge (SC) 20%, similar basis to CT, additive to CT (reduced from 32% in 2015 Budget). Petroleum Revenue Tax 50% (35% from 01/01/2016), charged for fields receiving development consent before 16/03/1993 on profits calculated by statutory method on field basis, deductible from income before CT and SC.

Sources: Ernst and Young (2014) *Global Oil and Gas Tax Guide*; National Conference of State Legislatures (NCSL, 2012) *Oil and Gas State Severance Taxes*; Department of Energy and Climate Change (DECC, 2015) *Oil and gas: taxation*.



Individual states also may offer tax incentives for CO<sub>2</sub>-EOR, usually reducing or making allowances against Severance Tax. Such incentives are available in Mississippi, North Dakota, Oklahoma, and are pending in Florida (NCSL, 2012).

### 2.2.2. Canada

Incentives for CO<sub>2</sub>-EOR in Canada are state specific. Saskatchewan offers reduced Crown Royalties and Production Tax (MOE, 2013) and also allows royalty credits of 30% of eligible research expenses for CCS projects and CO<sub>2</sub>-EOR projects that store CO<sub>2</sub> (CCS101, 2015). Alberta has an EOR program that caps royalties at 5% for eligible projects (Alberta Energy, 2014).

### 2.2.3. Malaysia

Malaysia offers increased annual investment allowances against Petroleum Revenue Tax for EOR developments; allowances are increased to at least 60%, some sources say up to 100%, from the normal 8% (Ernst & Young, 2013; USEIA, 2014).

### 2.2.4. Other regions

No information on specific incentives for CO<sub>2</sub>-EOR has been found for China, Norway or the UK. However, costs are likely to be fully deductible before income taxes. In the UK, it has been suggested that an extension of the Field Allowance system could be made to include CO<sub>2</sub>-EOR (Durusut and Pershad, 2014).

**Table 2. Incentives for EOR**

Region	Incentives applied to taxes on production value	Incentives applied to income taxes
<b>USA federal regime</b>		15% of costs of EOR deductible when oil price low and 100% of costs of tertiary injection deductible – both subject to repeal proposals. Tax credits \$10/t-CO <sub>2</sub> for CO <sub>2</sub> -EOR and \$20/t-CO <sub>2</sub> for CCS, available to companies capturing anthropogenic CO <sub>2</sub> ; total limited to 75 Mt-CO <sub>2</sub> .
<b>USA individual states</b>	Reductions or allowances against Severance Tax in Mississippi, North Dakota, Oklahoma, and pending in Florida.	
<b>Canada individual states</b>	Saskatchewan: Crown Royalty reduced to 1% of gross EOR revenue before investment pay-out, 20% of EOR operating income after investment pay-out. Freehold production tax reduced to 0% before investment pay-out, 8% of EOR operating income after investment pay-out. Alberta: Royalties capped at 5% for eligible projects.	
<b>Malaysia</b>		Annual investment allowances against PRT increased to 60-100%

Sources noted in text.

### 3. Availability of CO<sub>2</sub>, infrastructure and experience

This section looks at the availability of supply of CO<sub>2</sub> to potential EOR operations in the regions compared. This is considered in terms of absolute scale of CO<sub>2</sub> sources in the region, the location of sources, the existing, planned or potential CO<sub>2</sub> transport infrastructure available and the degree of maturity of EOR and/or CCS. Table 3 gives an approximate and subjective relative ranking of these factors across the regions compared (H, M, L – high, medium, low); brief descriptions for each region follow.

**Table 3. Ranking of CO<sub>2</sub> supply factors**

Region	Availability/proximity of CO <sub>2</sub>	CO <sub>2</sub> infrastructure	CO <sub>2</sub> -EOR/CCS maturity
USA onshore	H	H	H
USA Gulf of Mexico	M	M	M
Canada	M	M	H
Malaysia	L	L	L
China	M	M/L	H
Norway	L	L	H
UK	M/L	L	M

#### 3.1. USA onshore

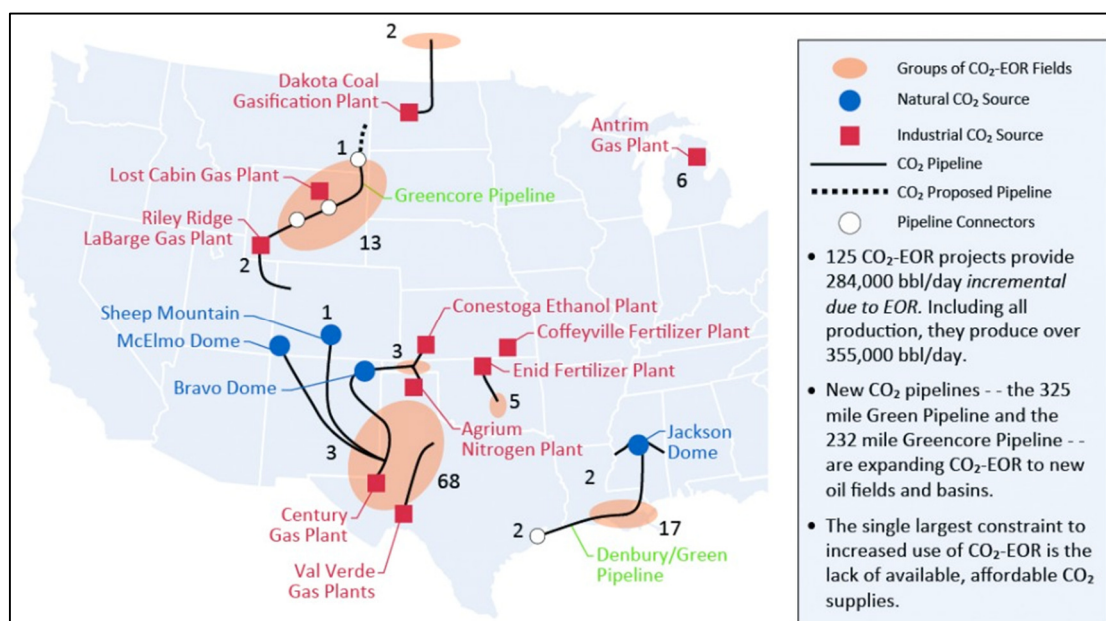
In the USA as a whole CO<sub>2</sub> emissions total over 5 Gt/yr (USEIA, 2015) and some 16% of this is emitted in Texas and Louisiana (Wikipedia, 2014) relatively close to a large proportion of USA onshore oil fields that are potentially suitable for CO<sub>2</sub>-EOR. While not all of this emission is from fixed sources suitable for capture, there is good regional availability of CO<sub>2</sub> in an overall sense.

There is an existing network of CO<sub>2</sub> supply pipelines in several areas of the USA with CO<sub>2</sub> produced from both natural and, increasingly, anthropogenic sources. Figure 1 summarises the position in 2013 and notes that the supply of CO<sub>2</sub> is a constraint on CO<sub>2</sub>-EOR developments (Kuuskraa and DiPietro, 2014). Since then a number of new anthropogenic CO<sub>2</sub> sources have come on line, particularly along the Gulf coast, and more are in development or planning stages (SCCS, 2015a). These developments are driven by the existing market demand for CO<sub>2</sub> from EOR and supported by the incentives outlined above.

However, there is a recognition that the natural sources of CO<sub>2</sub> are finite and some commentators strongly advocate increasing the capture of anthropogenic CO<sub>2</sub> as a means of increasing national oil output through CO<sub>2</sub>-EOR while also storing CO<sub>2</sub> (NEORI, 2012a; NEORI

2012b; Malone, Kuuskraa, DiPietro, 2014). Meanwhile, others sound a note of caution suggesting that EOR as generally operated may not lead to significant volumes of permanently stored CO<sub>2</sub> or to widespread deployment of CCS (Dooley, Dahowski, Davidson 2010).

The existing CO<sub>2</sub>-EOR operations onshore USA are the most extensive and best established globally, with over 120 projects operating (Figure 1). The experience with CCS in the USA is less but nonetheless leading, with an operational demonstration-scale industrial CCS project and at least one pilot-scale power plant CCS project utilising storage in saline formations.



Source: Kuuskraa and DiPietro, 2014.

**Figure 1. CO<sub>2</sub>-EOR operations, CO<sub>2</sub> sources and pipelines onshore USA**

### 3.2. USA Gulf of Mexico

The gross availability of anthropogenic CO<sub>2</sub> along the Gulf Coast is high with 25% of USA total emissions being from the five Gulf States: Texas, Louisiana, Mississippi, Alabama, Florida (Wikipedia, 2014). However, as described above, the availability of natural or captured CO<sub>2</sub> for supply to EOR projects is limited, and there are competing demands from established onshore operations.

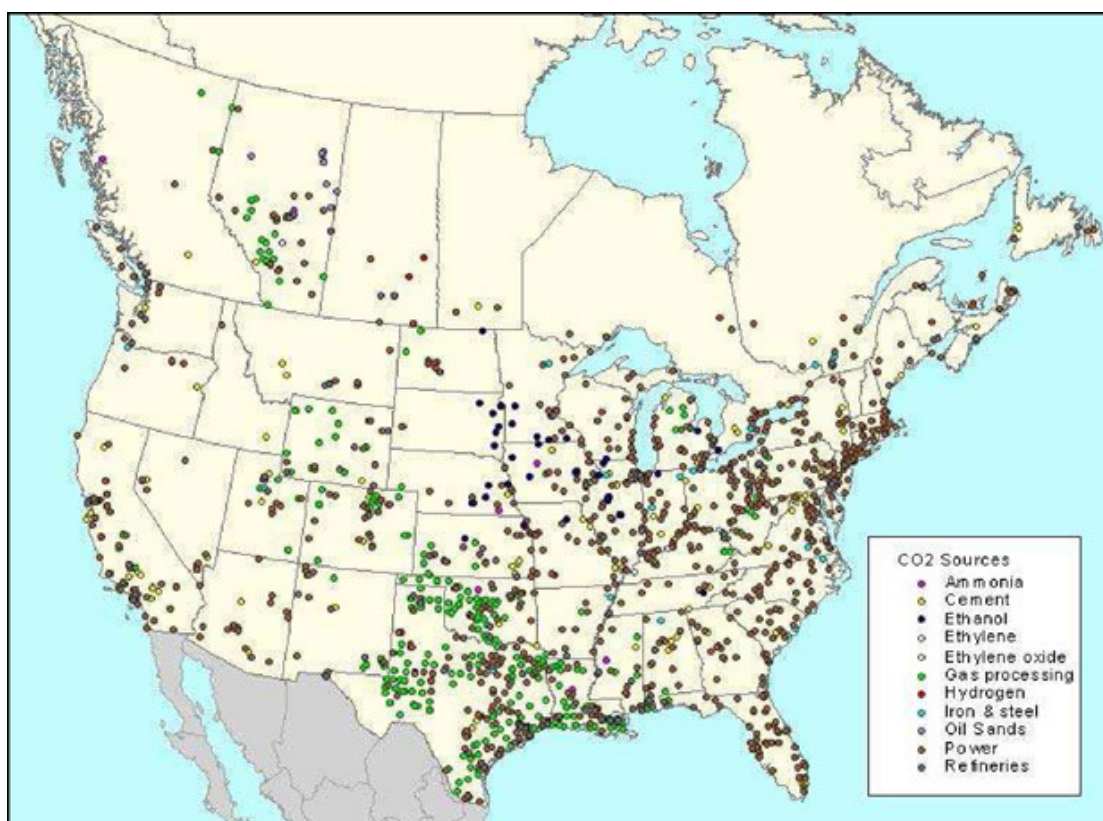
Malone and Kuuskraa (2013) have estimated that there are around 94 Mt/yr emissions from large point sources in the Gulf Coast area, potentially suitable for capture projects. There is existing CO<sub>2</sub> transport infrastructure in place on the Gulf coast – the Denbury Green Pipeline, commissioned in late 2010 – however, this has capacity for only c.17 Mt/yr, a level of supply that is expected to be taken up by onshore EOR operations (OGJ, 2011). Demand for CO<sub>2</sub> if offshore EOR operations were to be taken up strongly would be expected to be much higher than this (Malone and Kuuskraa, 2013) and significant development of supply and infrastructure would be needed.

Given the extent of onshore EOR developments in the Gulf States, it is perhaps surprising that there have been very few offshore EOR projects. Malone and Kuuskraa (2013) list five pilot

projects undertaken in the 1980s in Louisiana coastal waters. These were generally successful but did not lead to commercial developments.

### 3.3. Canada

The absolute level of CO<sub>2</sub> emissions in Canada varies widely by state with the highest emissions, at around 250 Mt-CO<sub>2</sub>-e/yr, in Alberta where most oil fields are also located (Environment Canada, 2014). Again, not all is from point sources suitable for capture, but the greatest concentration of large point sources is in Alberta as shown in Figure 2 (Dahowski *et al*, 2004).



Source: Dahowski *et al*, 2004

**Figure 2. Distribution of large CO<sub>2</sub> emission point sources in North America**

In 2006 110 Mt CO<sub>2</sub> was emitted from large point sources in Alberta and this was forecast to increase with projected further development of the oil sands industry. Of these emissions it was estimated that 35 Mt/yr could be captured at a cost of \$150/t-CO<sub>2</sub> (abated) or less (Ian Murray & Co, 2008). The majority of these sources are around Edmonton, which is relatively close to oilfields potentially suitable for CO<sub>2</sub>-EOR.

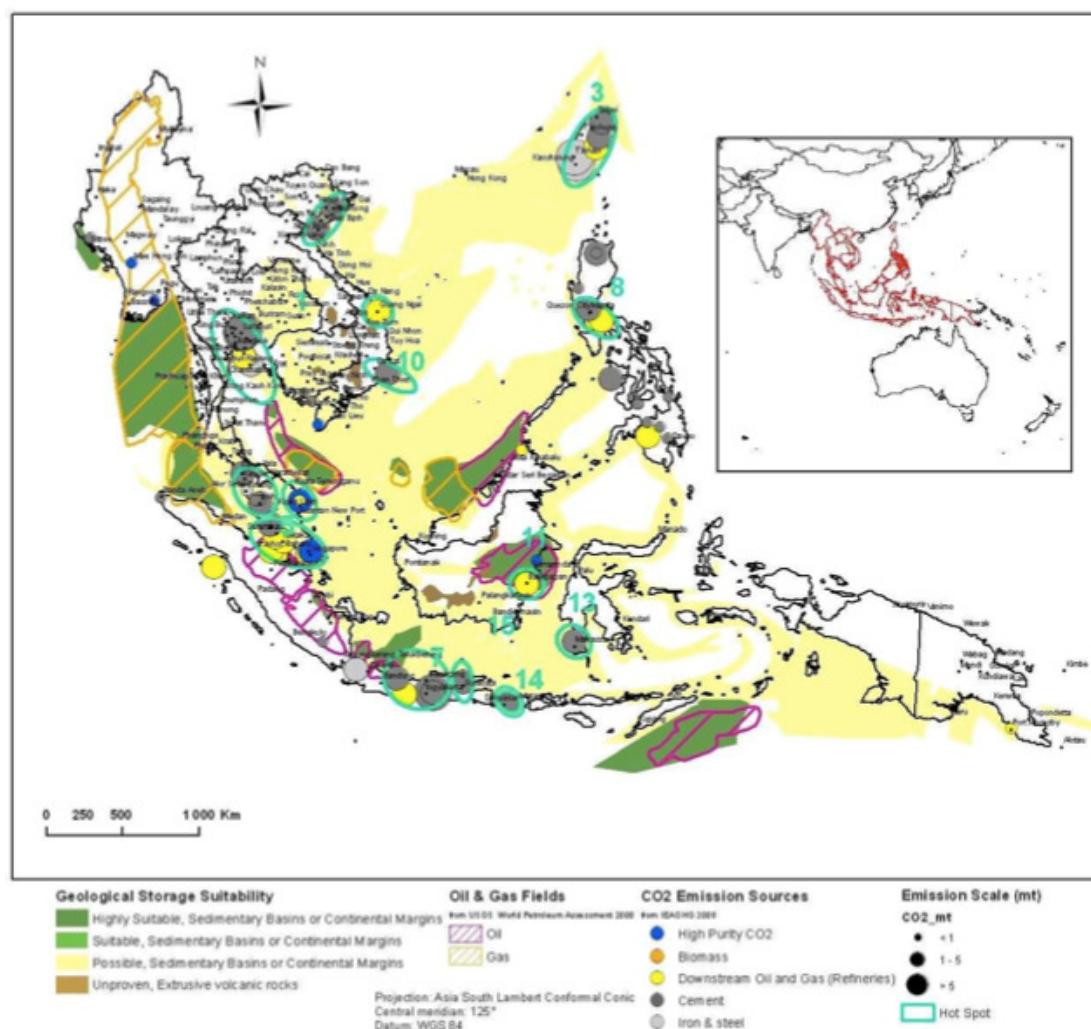
Although not as extensive as in the USA, Canada has experience of CO<sub>2</sub> pipelines in the cross-border line from Great Plains Synfuel Plant in North Dakota, to the well-established CO<sub>2</sub>-EOR operation at the Weyburn-Midale field in southern Saskatchewan. Two further CO<sub>2</sub> pipelines are also in construction or late planning stages. The Alberta Carbon Trunk Line will transport CO<sub>2</sub> some 240 km south from industrial and oil-upgrading facilities near Edmonton to the Clive Field for EOR (Enhance Energy, 2014). The Quest project, also near Edmonton, will pipe CO<sub>2</sub> about 65 km north for geological storage in a saline formation (Tucker, 2013).



With the projects mentioned above, the commercial-scale Boundary Dam project, long experience of CO<sub>2</sub>-EOR, several pilot projects running and further projects under development, Canada is a leader in the EOR and CCS fields, although the extent and maturity of development of CO<sub>2</sub>-EOR is lower than in the USA.

### 3.4. Malaysia

Malaysia as a whole has moderate CO<sub>2</sub> emissions, 229 Mt/yr in 2013 (Global Carbon Atlas, 2014). The majority of major point sources are sited on the west coast of the Malay Peninsular while the main productive oil fields are offshore, off the east coast or further east near the coasts of Sarawak, Brunei and Sabah as shown in Figure 3 (Le Gallo and Lecomte, 2011). The overland distance from the west coast industrial areas to the nearest oil fields is in the order of 500 km and would include crossing the central highlands. However, there are some smaller but significant clusters of high concentration emitters on the east coast (near Dungun and at Singapore) that would be closer to oil fields; these have been identified as potential early opportunities (Le Gallo and Lecomte, 2011).



Source: Le Gallo and Lecomte, 2011

**Figure 3. Qualitative source-sink matching in Southeast Asia**

Currently there is no large-scale infrastructure for CO<sub>2</sub> supply or transport in Malaysia beyond the industrial gases and food and drink sectors. However, there are existing large-scale gas

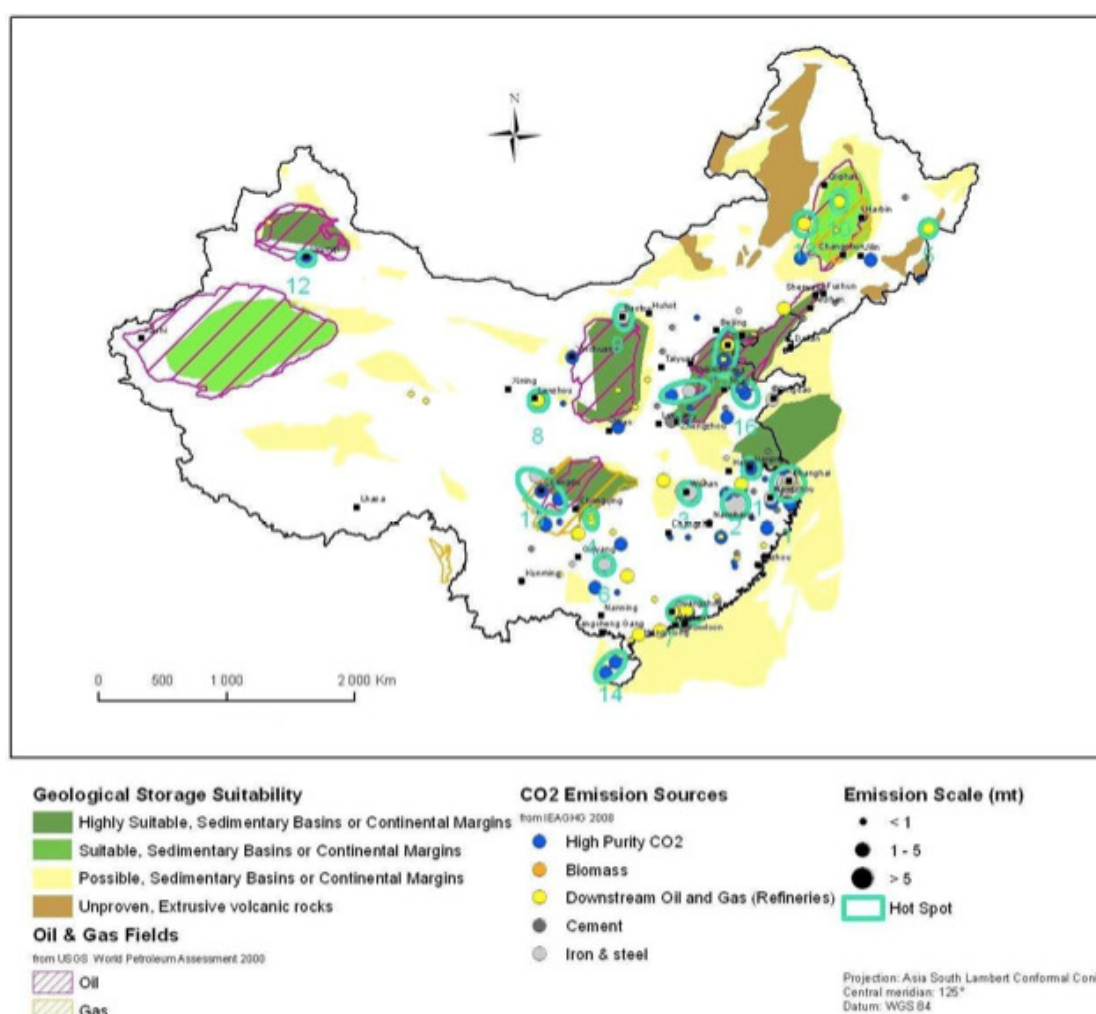
separation operations associated with some high CO<sub>2</sub> natural gas fields. The recently announced PETRONAS K5 Project will develop a new field with 70% CO<sub>2</sub> gas content using sub-sea separation technology and reinjecting CO<sub>2</sub> into an aquifer (SCCS, 2015b). EOR has also been considered for use of this separated CO<sub>2</sub> and the project may allow a supply of CO<sub>2</sub> closer to oil fields to be available in future.

The generally coastal locations of emitters in mainland Southeast Asia and the Malay Archipelago, together with the offshore locations of oil fields, suggest a CO<sub>2</sub> shipping system may be suitable for development of CO<sub>2</sub>-EOR in the region. This has been suggested by a number of studies mostly from Korean authors (Nam *et al*, 2013; and see Brownsort, 2015).

There are no known CCS proposals in Malaysia beyond the K5 project. PETRONAS and partners are developing EOR in a number of mature fields and there have been some pilot-scale trials (USEIA, 2014); however, it is not clear if these will use CO<sub>2</sub>.

### 3.5. China

China is the largest CO<sub>2</sub> emitter globally with annual emissions approaching 10 Gt in 2013 (Global Carbon Atlas, 2014). Several of the major industrial areas with a large number of point source emitters are situated close to major onshore oil and gas fields as shown in Figure 4. In addition coastal emission clusters are generally close to known offshore oil basins.



Source: Le Gallo and Lecomte, 2011

**Figure 4. Qualitative source-sink matching in China**

As yet, there is no integrated CO<sub>2</sub> transport infrastructure existing in China, however, there are a number of discrete pipeline projects in planning with some short sections existing. There is some experience of CO<sub>2</sub>-EOR in China with pilot projects existing in several areas including the Jilin and Shengli oil fields and the Ordos basin (SCCS, 2015a). The number of pilot projects existing and proposals for larger scale CCS and CO<sub>2</sub>-EOR projects suggest China might be considered with the leaders in the field, however, there are no large scale integrated projects operational yet and in several cases announced plans have been delayed.

### 3.6. Norway

Norway has low overall CO<sub>2</sub> emissions at just 58 Mt in 2013 (Global Carbon Atlas, 2014) with emitters generally spread out round the coasts in southern Norway and in the Oslo area. There is currently no integrated CO<sub>2</sub> transport infrastructure in Norway. Any CO<sub>2</sub>-EOR operations would likely be on the North Sea continental shelf west of the Norwegian Trench, making supply by pipeline more difficult, or in the Barents Sea, remote from CO<sub>2</sub> sources. Supply by CO<sub>2</sub> shipping has been studied and is considered feasible (Skagestad *et al*, 2011; Tel-Tek, 2012 ). Norway has experience of offshore EOR using gas and/or water injection but not CO<sub>2</sub>-EOR (NPD, 2009). However, it has experience of CO<sub>2</sub> injection in the longest established CCS operation, the Sleipner project, and has a number of pilot-scale capture projects and development proposals (SCCS, 2015a).

### 3.7. UK

Judging by similar criteria, the UK has medium to low availability of CO<sub>2</sub> in terms of potential for supply to EOR developments. While there is clearly no shortage of CO<sub>2</sub> emissions overall (462 Mt in 2013, Global Carbon Atlas, 2014) and clustering of large point source emitters may help by allowing efficient collection networks, the offshore location of all major oil fields is a barrier compared to some other global regions. One exception to this is the possibility of reusing specific existing gas infrastructure to provide CO<sub>2</sub> transport from central Scotland to the Central North Sea (Element Energy, 2014).

Currently there is no large-scale infrastructure for CO<sub>2</sub> supply or transport in the UK beyond the industrial gases and food and drink sectors. An unpublished study of CO<sub>2</sub> sources in the UK (Brownsort, 2013) estimated that there is in the order of 2.3 Mt/yr of high concentration CO<sub>2</sub> emitted from industry, however, most of this is widely dispersed and small scale. The most significant high concentration emissions, from ammonia manufacture, are in areas being considered for potential industrial CCS clusters.

The UK has no physical experience of large scale CCS or CO<sub>2</sub>-EOR. However, there is widespread use of water and/or gas injection at UK continental shelf production sites and a number of CCS projects have been or are being progressed through FEED studies. The industry expertise is available, particularly in terms of knowledge of offshore storage opportunities and from oil and gas industry experience in the North Sea.

## 4. Conclusions

The conditions for CO<sub>2</sub>-EOR have been compared between seven major oil-producing regions in terms of tax regime and incentives, general regional availability of CO<sub>2</sub>, existing or potential infrastructure to supply CO<sub>2</sub> and the degree of maturity of CO<sub>2</sub>-EOR and CCS in the region.

Broadly speaking, oil taxes can be divided into two groups based on either production volume/value or net income. The Asian and North American regions examined use both these groups but with different rates and a different balance between the groups in each region. The European regions studied (Norway and UK) only apply taxes on net income. It is difficult to make a straightforward comparison between the regions, as while corporate income taxes in European jurisdictions are much higher than in North America and Asia, production volume/value based taxes and royalties in the latter regions make up for this to some degree.

Specific incentives for CO<sub>2</sub>-EOR are offered in certain circumstances against taxes and/or royalties in USA, Canada and Malaysia, either by reductions in royalty or Severance Tax rate, or by tax allowances. In addition, tax credits for capture of anthropogenic CO<sub>2</sub> are offered to source companies in the USA in order to increase CO<sub>2</sub> supply availability, as a preferred alternative to incentivising EOR directly.

Differences in tax allowances, ring-fencing rules and incentives complicate the comparison between regions meaning it is difficult to predict what tax charges a development would be subject to without knowing many details of the operation and the company involved. A crude, judgement-based ranking of tax burden of CO<sub>2</sub>-EOR would suggest North America < Asia < Europe, but this should be used with caution and may not apply in all cases.

For the comparisons of CO<sub>2</sub> availability, supply/infrastructure and CO<sub>2</sub>-EOR/CCS maturity, to generalise, these factors are most advantageous in the onshore USA region, with Canada close behind, and least favourable in Malaysia, with Norway and the UK slightly more favoured. China is intermediate as a whole, but with more variation between factors. Offshore USA should share most of the advantages of the neighbouring onshore region, however, the existing demand onshore, together with the increased complexity of offshore operation, reduces the favourability in terms of these factors.

As an overall conclusion from the limited study presented, it is suggested that the UK would need to take major actions, such as significant financial incentives and state-supported provision of infrastructure, to be seen as a leading contender for investment in CO<sub>2</sub>-EOR by multinationals.



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